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STRESS TENSOR DETERMINATIONS WITH THE SOUTH AFRICAN BIAXIAL STRAIN CELL (DOORSTOPPER)

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STRESS TENSOR DETERMINATIONS WITH THE SOUTH AFRICAN BIAXIAL STRAIN CELL (DOORSTOPPER)

by

G. Herget*

SUMMARY

Ground stress determinations are carried out with increased frequency to assist in optimizing underground excavation layouts. Recently, many mining operations have been using the South African doorstopper method because of the simplicity of procedure and the relatively cheap equipment and materials used in the process.

Calculation of the ground stress tensor from doorstopper measurements is straightforward but requires a computer for quick analysis. At the Mining Research Laboratories a generic program has been used for many years but recently the need for a more userfriendly program became evident.

The following report defines the convention for installing doorstoppers and the use of the attached computer program to determine tensor components for E, N, vertical up direction, their errors, principal stresses, and their directions. A procedure for screening input data is given in Appendix B.

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DÉTERMINATION DU TENSEUR DES CONTRAINTES AU MOYEN DE LA CELLULE BIAXIALE DE DÉFORMATION UTILISÉE EN AFRIQUE DU SUD - (BUTOIR DE PORTE)

par

G. Herget*

SOMMAIRE

On a effectué la détermination des contraintes du sol plus fréquemment de façon à optimiser les tracés d'excavation souterraine. Récemment, plusieurs sociétés d'exploitation minières ont utilisé la méthode sud-africaine pour installer les butoirs de porte en raison de sa simplicité et de l'équipement et des matériaux relativement bon marché qu'elle nécessite.

Le calcul du tenseur des contraintes du sol à partir des mesures du butoir est simple mais nécessite l'utilisation d'un ordinateur pour l'analyse rapide des données. Les Laboratoires de recherche minière ont utilisé un programme générique depuis de nombreuses années mais récemment, la nécessité d'un programme convenant davantage aux usagers est devenue évidente.

Le rapport qui suit présente la façon de procéder pour installer les butoirs de porte et le mode d'emploi du programme informatique ci-joint qui permet de déterminer les composantes du tenseur pour E, N, la direction verticale vers le haut, les erreurs possibles, les contraintes principales et les directions triaxiales. Une technique pour vérifier les données d'entrée est présentée à l'annexe B.

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CONTENTS

	Page
SUMMARY	i
SOMMAIRE	ii
1. INTRODUCTION	1
2. DETERMINATION OF THE GROUND STRESS TENSOR	1
3. DATA INPUT	1
4. CONVENTION FOR DOORSTOPPER INSTALLATIONS	3
5. CALCULATION OF DIRECTION COSINES FOR STRAIN GAUGE DIRECTIONS	4
REFERENCES	11
APPENDIX A - COMPUTER PROGRAM	A-1
APPENDIX B - SCREENING OF STRAIN RECOVERY MEASUREMENTS	B-1

FIGURES

No.		
1.	Four gauge doorstopper strain cell	5
2.	Wiring diagram for four element rosette Doorstopper strain cells and accessories	6
3.	Graphical determination of direction cosine for strain gauge orientation	8
B-1	Positions and orientation of strain gauges for triaxial strain cell installing tool	B-4
B-2	Cumulative distribution of observed deviations from group means	B-9

TABLES

1.	Orientation of strain gauges to drillhole direction	4
B-1	Strain readings obtained with triaxial South African strain cell in one drill hole	B-3
B-2	Difference from group means	B-7

1. INTRODUCTION

Ground stress determinations are a necessity for the application of numerical modelling to determine the optimum mining layout for mining operations. Calculations of the ground stress tensor from stress recovery measurements with strain gauges is straightforward but cumbersome and computer calculations are required in all cases.

With the increased use of the doorstopper method for ground stress determinations, an existing computer program was updated to assist mining companies and other interested parties to quickly analyze results from stress determination programs.

Appendix B lists a procedure for the screening of fielddata from strain recovery measurements before pooling them for data analysis.

2. DETERMINATION OF THE GROUND STRESS TENSOR

The computer program described below is written in Basic and determines the best fit ground stress tensor components based on strain gauge readings and physical properties of rock. The analysis follows, in essence, the approach described by L. Panek in 1965 (1). Modifications are necessary, however, to accommodate the special requirements of the doorstopper measuring method which are described by Leeman 1964 (2) and Gray and Barron 1969 (3).

A generic computer program was written in 1974 at the Elliot Lake Laboratory by G. Herget. Its repeated use indicated that standardization of strain gauge rosette installation procedures would allow analysis to proceed more rapidly and with fewer errors. It also would allow personnel not familiar with tensor analysis to carry out the required data analysis. The attached program fills these requirements and is written in Basic (Appendix A).

3. DATA INPUT

The program has been written to allow quick implementation and does not possess any format statements in regard to input and output. Data input is written directly into the program and allows easy checking of program functions.

Dimension Statements

According to the number of observations (G), the dimension statement for K needs to be defined as K(G + 1, 42).

Example: For G = 24 strain readings define K(25, 42)

Elastic Modulus

The elastic modulus (E) is defined in 10^6 psi to give tensor components in psi. If E is given in MPa, the tensor components will be returned in MPa.

Example: For elastic modulus = 9.28×10^6 psi E = 9.28

Poisson's Ratio

Poisson's ratio (N) is defined at line number 120.

Data Statements

For each doorstopper installation the strain gauges are installed in a standard orientation to the borehole direction. Therefore, only the borehole direction is defined and the program expects strain gauge readings to follow orientations of horizontal, +45°, +90° and 135°.

```
400  DATA 248,16
500  DATA 913,91,915,49,9999901
600  DATA 923,138,925,68,999902
700  DATA 933,177,935,87,999903
800  DATA 943,122,945,65,999904
900  DATA 248,62
```

line 400: borehole direction by azimuth (e.g. 248) and inclination (e.g. +16° up)

line 500: 913 identifies borehole number 9, gauge orientation 1, test number 3; strain recovery reading 91, 915 as above but recording test number 5, 999901 is a control number which identifies that all readings of gauge orientation 1 (horizontal) have been read

line 600: as above for gauge orientation 2 (+45°)

line 700: as above for gauge orientation 3 (+90°)

line 800: as above for gauge orientation 4 (+135°) and signals a new set of measurements to be expected from a new borehole by 999904

line 1800: 999999 End of data

Calibration Factors

These factors are required to take care of the stress concentration effects occurring at the end of a borehole and are based on reference 3.

```
4700 A = (1.29+.51*N-.22*N^2+.58N^3)/E
4800 B = (-.05-1.41*N)/E
4900 C = (-.46-.55*N+.35*N^2+1.5*N^3)/E
```

4. CONVENTION FOR DOORSTOPPER INSTALLATIONS

Doorstoppers carrying strain gauge rosettes can be installed in any way desired on the flat bottom of the drillhole, so long as the analysis is carried out with the clear understanding of which reading was obtained in what direction. Each direction is defined by direction cosines which can be determined by graphical plotting or numerically.

To speed up the analysis and avoid errors, it is suggested that doorstoppers be installed in drillholes in a standard orientation. Throughout the program a rectangular coordinate system is used with axes oriented East, North, and Vertical up.

For tensor analysis, the measuring direction is referenced to an observer standing inside an excavation and gauge directions are seen as mounted on walls, roof and floor. In other words, the reference to the rosette on the doorstopper is seen from the back end where the plug pins are visible. In case of the triaxial strain cell the observer describes the strain gauge for each rosette by looking at each rosette from the inside of the triaxial strain cell.

The switch box supplied with the doorstopper equipment switches through positions 1, 2, 3 and 4 to read the individual gauges. When looking

at the doorstopper from the back end, the sequence of switching is anti-clockwise, starting with switch position 1 for the horizontal gauge pointing to the right. The anti-clockwise switching sequence contacts each time a strain gauge with a higher θ angle, similar to the convention for polar coordinates with θ increasing anti-clockwise from the x-axis. Accordingly, the strain gauge orientations for the doorstopper are defined as in Table 1 and Fig. 1 and the wiring diagram of Fig. 2.

Table 1 - Orientation of strain gauges to drillhole direction with observer looking at back end of doorstopper or to bottom of hole

Name	θ	Switch Position	Wiring Diagram	CSIR Convention
Horizontal Gauge	0	1	A	H
45 Degree Gauge	45	2	C	-45 (135)
30 Degree Gauge	90	3	B	V
135 Degree Gauge	135	4	D	+45

In a vertical hole the azimuth for the borehole direction is undefined. It is suggested to install the horizontal gauge in direction E and give the borehole azimuth and inclination as 000/90.

The main rule is to remember that the horizontal gauge is mounted horizontally and that the switch positions 1, 2, 3, 4 switch from the horizontal gauge (switch position 1) anti-clockwise through all gauges in 45° steps for an observer looking down the drillhole. Looking down the drillhole means looking at the gauge rosette from the connector end. (This is different from the CSIR convention which names gauges by looking at the gauge face and thus the switch position (2) which corresponds to the θ = 45° gauge is called in CSIR convention the -45 (135°) gauge).

5. CALCULATION OF DIRECTION COSINES FOR STRAIN GAUGE DIRECTIONS

As shown in Fig. 1, a fixed relationship is maintained for the direction of strain gauges in regard to the borehole direction. Boreholes are

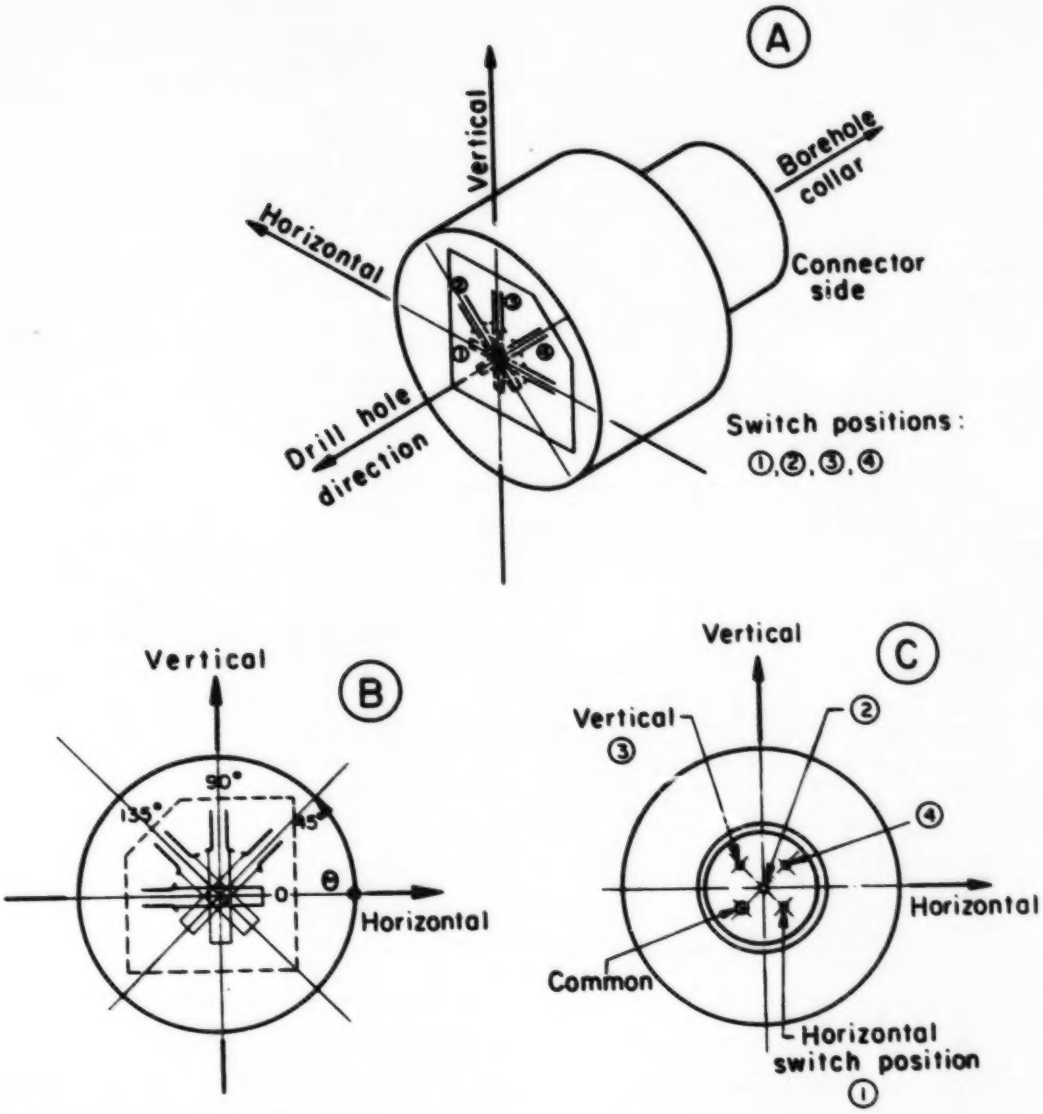


Fig. 1 - Four gauge doorstopper strain cell

A) Perspective view

B) View of gauges from connector side corresponding to viewing down the drill hole

C) Pin positions for gauges

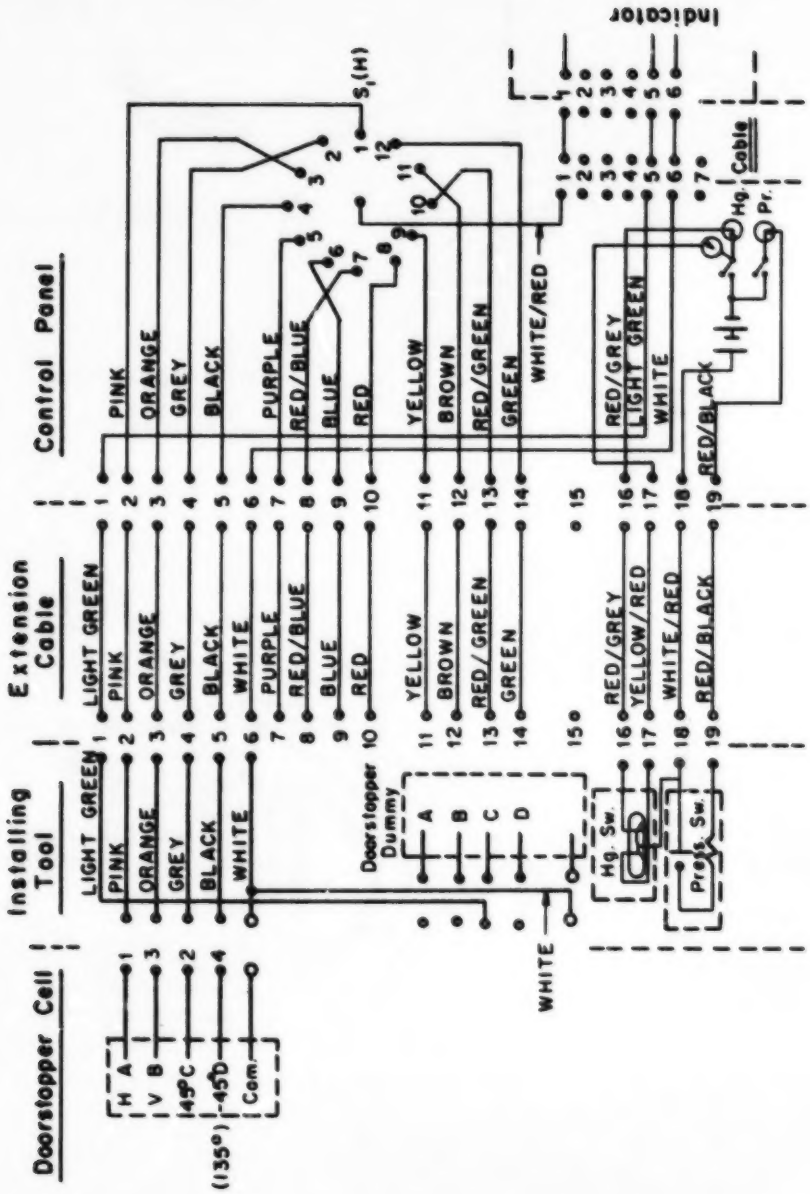


Fig. 2 - Wiring diagram for four element rosette Doorstopper strain cells and accessories.

defined by azimuth and inclination, with azimuth defined as the angle clockwise from N and the inclination as the angle of hole direction upward (positive angle) or downward (negative angle).

Borehole Direction

If a borehole is drilled with an azimuth of 293°, and an inclination of +16°, the coordinates of the borehole direction in relation to the geographic coordinates east (x), north (y), vertical up (z) are determined as follows:

$$x = r \cos \varphi \cos \lambda$$
$$y = r \cos \varphi \sin \lambda$$
$$z = r \sin \varphi$$

With r = unity, and φ representing the inclination from horizontal with positive up, λ is taken anti-clockwise from the x-axis. As azimuth is given from N clockwise, an adjustment is made for λ = 450 - Azimuth.

$$x = \cos 16 \cdot \cos(450-293) = -0.8848 = \cos 152.2$$
$$y = \cos 16 \cdot \sin(450-293) = 0.3756 = \cos 67.9$$
$$z = \sin 16 = 0.2756 = \cos 74.0$$

Strain gauges are installed in a plane at right angles to the borehole, with θ defined as angle from horizontal anti-clockwise for a viewer looking from the collar to the flattened bottom of the drillhole.

$S_1 = 0$
$S_2 = +45$
$S_3 = +90$
$S_4 = +135°$

To illustrate the geometrical problem of referencing these directions, the angles are identified graphically in Fig. 3. The plot uses an equal area net, representing the upper hemisphere. By rotation of the plot over an equal area net, the direction cosine angle from the direction of the strain gauge to the geographic coordinate E, N, vertical up can be read directly, e.g., for S_2 = 64°, 54°, 47°.

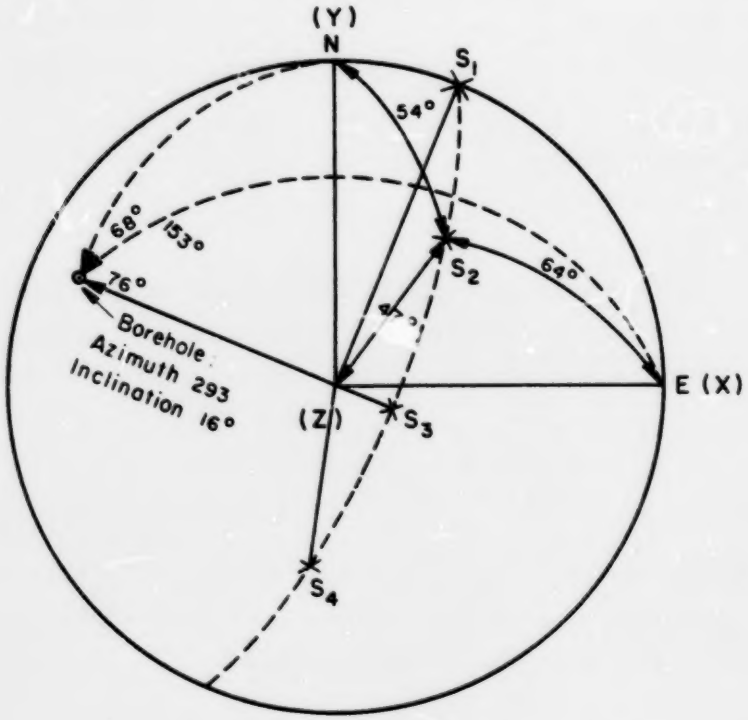
Numerical determination is, however, more accurate. For repetitive tasks it is more convenient and is derived as follows:

S_1 - direction

S_1 is always installed in the horizontal direction, and thus has the azimuth:

borehole azimuth +90°, e.g., 293 + 90 and an inclination of 0. Thus

$$x = \cos 0 \cdot \cos (450-383) = 0.3907 = \cos 67°$$
$$y = \cos 0 \cdot \sin (450-383) = 0.9205 = \cos 23°$$
$$z = \sin 0 = 0 = \cos 90°$$



Cosine Angles

	To:	Borehole	S_1	S_2	S_3	S_4
From:	x(E)	153	67	64	75	95
	y(N)	68	23	54	95	136
	z(vertical up)	74	90	47	16	47

Fig. 3 - Graphical determination of direction cosine for strain gauge orientation.

S_3-Direction

S_3 is similar, with an azimuth of 293 + 180 = 473 and an inclination of 90 minus the borehole inclination, e.g., 90 - 16 = 74°

$$x = \cos 74° \cdot \cos (450-473) = 0.2537 = \cos 75.3°$$
$$y = \cos 74° \cdot \sin (450-473) = -0.1077 = \cos 96.2°$$
$$z = \sin 74° = 0.9613 = \cos 16.0°$$

The directions of S_3-gauge, S_1-gauge, and the borehole (B) represent a right handed rectangular coordinate system. The directions of S_2 and S_4 can be expressed in terms of the S_3, S_1 and borehole directions and then transformed to the east, north, vertical coordinates. The angle of S_2, S_4 to S_3, S_1, B are as follows:

	S_3	S_1	B
S_4	45	135	90
S_2	45	45	90

S_4-Direction

The coordinate expressed in direction cosine angle of point S_4 to S_3, S_1, B are:

$$x' = S_4S_3 = 45,\ y' = S_4S_1 = 135,\ z' = S_4B = 90.$$

Transformation to the East, North, vertical axes allows definition of direction S_4 in the coordinates of E, N, V. These new coordinates are:

$$x^* = a_{11} \cdot x' + a_{21}y' + a_{31}z'$$
$$y^* = a_{12} \cdot x' + a_{22}y' + a_{32}z'$$
$$z^* = a_{13} \cdot x' + a_{23}y' + a_{33}z'$$

With a_{ik} defined as follows:

$$a_{11} = \cos(x',x^*) \quad a_{12} = \cos(x',y^*) \quad a_{13} = \cos(x',z^*)$$
$$a_{21} = \cos(y',x^*) \quad a_{22} = \cos(y',y^*) \quad a_{23} = \cos(y',z^*)$$
$$a_{31} = \cos(z',x^*) \quad a_{32} = \cos(z',y^*) \quad a_{33} = \cos(z',z^*)$$

With the first index relating to the first coordinate system (S_3, S_1, B) and the second index refers to the coordinate system for which the transformation is intended (E, N, V).

	E (x^*)	N (y^*)	V (z^*)
S_3	75	96	16
S_1	67	23	90
B	152	68	74

$x^* = \cos 75 \cdot \cos 45 + \cos 67 \cdot \cos 135 + \cos 152 \cdot \cos 30 = \cos 96$
$y^* = \cos 96 \cdot \cos 45 + \cos 23 \cdot \cos 135 + \cos 68 \cdot \cos 30 = \cos 137$
$z^* = \cos 16 \cdot \cos 45 + \cos 90 \cdot \cos 135 + \cos 74 \cdot \cos 30 = \cos 47$

S_2-direction

Following the same process we obtain for S_2

$x^* = \cos 75 \cdot \cos 45 + \cos 67 \cdot \cos 45 + \cos 152 \cdot \cos 90 = \cos 63$
$y^* = \cos 96 \cdot \cos 45 + \cos 23 \cdot \cos 45 + \cos 68 \cdot \cos 90 = \cos 55$
$z^* = \cos 16 \cdot \cos 45 + \cos 90 \cdot \cos 45 + \cos 74 \cdot \cos 90 = \cos 47$

For the complete program the direction cosines are correlated as follows:

$A(1,1) = S_3x$, $A(2,1) = S_1x$, $A(3,1) = Bx$
$A(1,2) = S_3y$, $A(2,2) = S_1y$, $A(3,2) = By$
$A(1,3) = C_3z$, $A(2,3) = S_1z$, $A(3,3) = Bz$
$A(4,1) = S_4x$, $A(4,2) = S_4y$, $A(4,3) = S_4z$
$A(5,1) = S_2x$, $A(5,2) = S_2y$, $A(5,3) = S_2z$

With x, y, z the rectangular coordinates and B = borehole direction.

REFERENCES

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2. Leeman, E.R. "The measurement of stress in rock, parts I, II, III"; J.S. Africa Inst. Min. Metall. 65:45-114 and 254-284; 1964.

3. Gray, W.G. and Barron, K. "Stress determination from strain relief measurements on the end of boreholes, planning, data evaluation and error assessment"; Int'l. Symposium on Determination of Stress in Rock Masses; Lisbon, Portugal; 1969.

4. Herget, G. "Program to calculate ground stress tensor from doorstopper strain readings CALL/360/1972".

5. Davies, O.L. "Statistical methods in research and production"; Oliver and Boyd 396; New York; 1967.

APPENDIX A - COMPUTER PROGRAM

```
10 REM PROGRAM CALCULATES BEST FIT STRESS TENSOR FOR E-W,N-S,VERTICAL
20 REM COORDINATES FROM STRAIN RECOVERY MEASUREMENTS WITH FOUR GAUGE
30 REM DOORSTOPPER.DATA ARE ENTERED AT 400:BOREHOLE AZIMUTH/INCLINATION,
40 REM NUMBER OF STRAIN READING,STRAIN RECOVERY,CONTROL NUMBER,STRAIN
42 REM READINGS ARE ENTERED IN SEQUENCE OF HORIZONTAL,+45,VERTICAL,
44 REM +135 ANTICLOCKWISE FOR VIEWER LOOKING INTO BOREHOLE.G=NUMBER OF
46 REM OBSERVATIONS,E=ELASTIC MODULUS,N=POISSONS RATIO,DIM K(G+1,42).
48 REM HERGET-CYBER BASIC/JUNE 6,1985.
50 OPTION BASE 1
60 FILE #2="COEFF"
70 DIM K(13,42)
80 DIM H(10),A2(40)
90 DIM F(6,6),Z(6,6),R(2,3),L(3,3),M(2,3),D(6,7),W(6),N(6),A(5,3)
95 PRINT"TENSOR ANALYSIS OF 4-GAUGE DOORSTOPPER READINGS (HERGET/1985)"
100 G=12
110 E=9.280
120 N=.250
130 O=G+1
140 READ A,I
150 F=0.0174532930
160 F1=0*F
170 F2=45*F
180 F3=90*F
190 F4=135*F
200 F5=180*F
210 F6=450*F
220 A1=A*F
230 I1=I*F
240 A(1,1)=COS(F3-I1)*COS(F6-(A1+F5))
250 A(2,1)=COS(F1)*COS(F6-(A1+F3))
260 A(3,1)=COS(I1)*COS(F6-A1)
270 A(1,2)=COS(F3-I1)*SIN(F6-(A1+F5))
280 A(2,2)=COS(F1)*SIN(F6-(A1+F3))
290 A(3,2)=COS(I1)*SIN(F6-A1)
300 A(1,3)=SIN(F3-I1)
310 A(2,3)=SIN(F1)
320 A(3,3)=SIN(I1)
330 A(4,1)=A(1,1)*COS(F2)+A(2,1)*COS(F4)+A(3,1)*COS(F3)
340 A(4,2)=A(1,2)*COS(F2)+A(2,2)*COS(F4)+A(3,2)*COS(F3)
350 A(4,3)=A(1,3)*COS(F2)+A(2,3)*COS(F4)+A(3,3)*COS(F3)
360 A(5,1)=A(1,1)*COS(F2)+A(2,1)*COS(F2)+A(3,1)*COS(F3)
370 A(5,2)=A(1,2)*COS(F2)+A(2,2)*COS(F2)+A(3,2)*COS(F3)
380 A(5,3)=A(1,3)*COS(F2)+A(2,3)*COS(F2)+A(3,3)*COS(F3)
400 DATA 248,16
500 DATA 913,91,999901
600 DATA 923,138,999902
700 DATA 933,177,999903
800 DATA 943,122,999904
900 DATA 248,62
1000 DATA 1011,111,999901
1100 DATA 1021,37,999902
1200 DATA 1031,-42,999903
1300 DATA 1041,14,999904
1400 DATA 270,16
1500 DATA 1211,-83,999901
1600 DATA 1221,33,999902
1700 DATA 1231,287,999903
1800 DATA 1241,172,999999
1900 PRINT"BOREHOLE AZIMUTH AND INCLINATION"
1950 PRINT A,I
2000 L(2,1)=A(3,1)
2100 L(2,2)=A(3,2)
2200 L(2,3)=A(3,3)
2300 L(1,1)=A(2,1)
2400 L(1,2)=A(2,2)
2500 L(1,3)=A(2,3)
```

```
2550 PRINT"HORIZONTAL GAUGE"
2600 GOTO 3900
2700 L(1,1)=A(5,1)
2800 L(1,2)=A(5,2)
2900 L(1,3)=A(5,3)
2950 PRINT"45 DEGREE GAUGE"
3000 GOTO 3900
3100 L(1,1)=A(1,1)
3200 L(1,2)=A(1,2)
3300 L(1,3)=A(1,3)
3350 PRINT"90 DEGREE GAUGE"
3400 GOTO 3900
3500 L(1,1)=A(4,1)
3600 L(1,2)=A(4,2)
3700 L(1,3)=A(4,3)
3750 PRINT"135 DEGREE GAUGE"
3800 GOTO 3900
3900 READ H
4000 IF H=999901 GOTO 2700
4100 IF H=999902 GOTO 3100
4200 IF H=999903 GOTO 3500
4300 IF H=999904 GOTO 140
4400 IF H=999999 GOTO 8200
4500 READ U
4600 A2(0)=A2(0)+U**2
4700 A=(1.29+.51*N-.22*N^2+.58*N^3)/E
4800 B=(-.05-1.41*N)/E
4900 C=(-.46-.55*N+.35*N^2+1.5*N^3)/E
6000 L(3,1)=L(1,2)*L(2,3)-L(1,3)*L(2,2)
6100 L(3,2)=L(1,3)*L(2,1)-L(1,1)*L(2,3)
6200 L(3,3)=L(1,1)*L(2,2)-L(1,2)*L(2,1)
6300 P(1)=A*L(1,1)*L(1,1)+B*L(3,1)*L(3,1)+C*L(2,1)*L(2,1)
6400 P(2)=A*L(1,2)*L(1,2)+B*L(3,2)*L(3,2)+C*L(2,2)*L(2,2)
6500 P(3)=A*L(1,3)*L(1,3)+B*L(3,3)*L(3,3)+C*L(2,3)*L(2,3)
6600 P(4)=2*(A*L(1,1)*L(1,2)+B*L(3,1)*L(3,2)+C*L(2,1)*L(2,2))
6700 P(5)=2*(A*L(1,2)*L(1,3)+B*L(3,2)*L(3,3)+C*L(2,2)*L(2,3))
6800 P(6)=2*(A*L(1,3)*L(1,1)+B*L(3,3)*L(3,1)+C*L(2,3)*L(2,1))
6900 FOR Y=1 TO 6
7000 FOR X=1 TO 6
7100 D(Y,X)=P(Y)*P(X)
7200 NEXT X
7300 NEXT Y
7400 FOR Y=1 TO 6
7500 D(Y,7)=U*P(Y)
7600 NEXT Y
7700 PRINT H,U,E,N
7800 FOR X=1 TO 6
7900 PRINT #2,D(X,1),D(X,2),D(X,3),D(X,4),D(X,5),D(X,6),D(X,7)
8000 NEXT X
8100 GOTO 3900
8200 CLOSE #2
8300 FILE #1="COEFF"
8400 FILE #3="MAX"
8500 FOR R=1 TO G
8600 FOR C=1 TO 42
8700 INPUT #1,K(R,C)
8800 K(0,C)=K(0,C)+K(R,C)
8900 NEXT C
9000 NEXT R
9100 FOR C=1 TO 6
9200 PRINT #3,K(0,C)
9300 NEXT C
9400 FOR C=8 TO 13
9500 PRINT #3,K(0,C)
9600 NEXT C
9700 FOR C=15 TO 20
```

```
9800 PRINT #3,K(0,C)
9900 NEXT C
10000 FOR C= 22 TO 27
10100 PRINT #3,K(0,C)
10200 NEXT C
10300 FOR C= 29 TO 34
10400 PRINT #3,K(0,C)
10500 NEXT C
10600 FOR C=36 TO 41
10700 PRINT #3,K(0,C)
10800 NEXT C
10900 CLOSE #1
11000 CLOSE #3
11100 FILE #4="MAX"
11200 MAT INPUT #4,F
11300 GOSUB 15000
11400 PRINT"TENSOR COMPONENTS (PSI) IN E-W,N-S,VERTICAL DIRECTIONS"
11500 FOR X=1 TO 6
11600 B(X)=Z(X,1)*K(0,7)+Z(X,2)*K(0,14)+Z(X,3)*K(0,21)+Z(X,4)*K(0,28)
11700 C(X)=Z(X,5)*K(0,35)+Z(X,6)*K(0,42)
11800 E(X)=B(X)+C(X)
11900 PRINT E(X)
12000 NEXT X
12100 FOR X=1 TO 6
12200 N(X)=Z(X,X)^.50
12300 NEXT X
12400 FOR X=1 TO 6
12500 C=X*7
12600 T(X)=K(0,C)*E(X)
12700 NEXT X
12800 Q=A2(0)-(T(1)+T(2)+T(3)+T(4)+T(5)+T(6))
12900 PRINT"RESIDUAL SUM OF SQUARES"
13000 PRINT Q
13100 S=(Q/(G-6))^.50
13200 PRINT"STANDARD DEVIATION ABOUT FITTED REGRESSION"
13300 PRINT S
13400 PRINT "STANDARD ERROR FOR TENSOR COMPONENTS"
13500 FOR X=1 TO 6
13600 W(X)=S*N(X)
13700 PRINT W(X)
13800 NEXT X
13900 CLOSE #4
14000 GOTO 15470
15000 REM START OF SUBROUTINE FOR MATRIX INVERSION
15100 R5=6
15110 FOR J=1 TO R5
15150 Z(J,J)=1
15160 NEXT J
15170 FOR J=1 TO R5
15180 FOR I=J TO R5
15190 IF F(I,J)<>0 THEN 15240
15200 NEXT I
15210 PRINT"SINGULAR MATRIX"
15230 GOTO 15000
15240 FOR K=1 TO R5
15250 S1=F(J,K)
15260 F(J,K)=F(I,K)
15270 F(I,K)=S1
15280 S1=Z(J,K)
15290 Z(J,K)=Z(I,K)
15300 Z(I,K)=S1
15310 NEXT K
15320 T=1/F(J,J)
15330 FOR K=1 TO R5
15340 F(J,K)=T*F(J,K)
15350 Z(J,K)=T*Z(J,K)
```

```
15360 NEXT K
15370 FOR L=1 TO R5
15380 IF L=J THEN 15440
15390 T=-F(L,J)
15400 FOR K=1 TO R5
15410 F(L,K)=F(L,K)+T*F(J,K)
15420 Z(L,K)=Z(L,K)+T*Z(J,K)
15430 NEXT K
15440 NEXT L
15450 NEXT J
15460 RETURN
15470 REM CALCULATION OF PRINCIPAL STRESSES
15480 X=E(1)
15490 Y=E(2)
15500 Z=E(3)
15510 X2=E(4)
15520 Y3=E(5)
15530 Z1=E(6)
15540 I1=-X-Y-Z
15550 I2=X*Y+X*Z+Y*Z-X2**2-Z1**2-Y3**2
15560 I3=-X*Y*Z-2*Y3*Z1*X2+X*Y3**2+Y*Z1**2+Z*X2**2
15570 P=I2-(I1**2)/3
15580 Q=(2*I1**3)/27-I1*I2/3+I3
15590 R=((-P**3)/27)**.5
15600 R1=-0.5*Q/R
15620 C1=R1
15630 GOSUB 15980
15640 A0=T1
15650 A1=A0=A0*57.295778
15660 A2=A1/3
15670 A3=A2/57.295778
15680 A4=COS(A3)
15690 A5=COS(A3+2.0943952)
15700 A6=COS(A3+4.1887903)
15710 P1=2*(R**0.3333)*A4
15720 P2=2*(R**0.3333)*A5
15730 P3=2*(R**0.3333)*A6
15740 S(1)=P1-I1/3
15750 S(2)=P2-I1/3
15760 S(3)=P3-I1/3
15765 REM CALCULATION OF DIR. COS TO AXES X,Y,Z
15770 FOR B=1 TO 3
15780 K1=(((X-S(B))/X2)-(X2/(Y-S(B))))/(Y3/(Y-S(B))-Z1/X2)
15790 K2=((X2/Y3)-(Z1/(Z-S(B))))/((Y3/(Z-S(B)))-((Y-S(B))/Y3))
15820 B(B)=(1/(1+K2**2+K1**2))**0.5
15830 C1=B(B)
15840 GOSUB 15980
15850 U(B)=57.296*T1
15860 E(B)=K2*B(B)
15870 C1=E(B)
15880 GOSUB 15980
15890 V(B)=57.296*T1
15900 H(B)=K1*B(B)
15910 C1=H(B)
15920 GOSUB 15980
15930 N(B)=57.296*T1
15932 IF E(B)=0 GOTO 15936
15934 GOTO 15948
15936 IF B(B)> 0 GOTO 15940
15938 IF B(B) <0 GOTO 15944
15940 A1(B)=1.570796
15942 GOTO 15955
15944 A1(B)=4.712389
15946 GOTO 15955
15948 IF E(B)<0 GOTO 15954
15950 A1(B)=ATN(B(B)/E(B))
```

```
15952 GOTO 15955
15954 A1(B)=3.141593+ATN(B(B)/E(B))
15955 A2(B)=A1(B)*57.296
15956 I(B)=90-N(B)
15958 PRINT"PRINCIPAL STRESS  AZIMUTH FROM NORTH/INCLINATION(-DOWN)"
15960 PRINT S(B),A2(B),I(B)
15962 PRINT"ARCOS TO AXES E,N,VERTICAL(UP)"
15964 PRINT U(B),V(B),N(B)
15966 NEXT B
15970 STOP
15980 REM CALCULATION OF ARC COS WITH ARC TAN
15990 IF C1=0 THEN 16000 ELSE 16020
16000 T1=1.5708
16010 GOTO 16080
16020 C2=C1**2
16030 S2=1-C2
16040 T2=(S2/C2)**0.5
16050 T1=ATN(T2)
16060 IF C1<0 THEN 16070 ELSE 16080
16070 T1=3.14159-T1
16080 RETURN
16090 END
```

```
..RUN,BASIC

        34500B CM USED
    1.070 CP SECONDS COMPILATION TIME
```

OUTPUT

```
TENSOR ANALYSIS OF 4-GAUGE DOORSTOPPER READINGS (HERGET/1985)
BOREHOLE AZIMUTH AND INCLINATION
 248              16
HORIZONTAL GAUGE
 913              91              9.28            .25
45 DEGREE GAUGE
 923              138             9.28            .25
90 DEGREE GAUGE
 933              177             9.28            .25
135 DEGREE GAUGE
 943              122             9.28            .25
BOREHOLE AZIMUTH AND INCLINATION
 248              62
HORIZONTAL GAUGE
 1011             111             9.28            .25
45 DEGREE GAUGE
 1021             37              9.28            .25
90 DEGREE GAUGE
 1031             -42             9.28            .25
135 DEGREE GAUGE
 1041             14              9.28            .25
BOREHOLE AZIMUTH AND INCLINATION
 270              16
HORIZONTAL GAUGE
 1211             -83             9.28            .25
45 DEGREE GAUGE
 1221             33              9.28            .25
90 DEGREE GAUGE
 1231             287             9.28            .25
135 DEGREE GAUGE
 1241             172             9.28            .25
TENSOR COMPONENTS (PSI) IN E-W,N-S,VERTICAL DIRECTIONS
 2367.24
 2104.19
 3571.25
-297.798
-145.444
-664.708
```

```
RESIDUAL SUM OF SQUARES
 29715.1
STANDARD DEVIATION ABOUT FITTED REGRESSION
 70.3741
STANDARD ERROR FOR TENSOR COMPONENTS
 3474.13
 2304.15
 2908.28
 420.783
 336.04
 1289.6
PRINCIPAL STRESS  AZIMUTH FROM NORTH/INCLINATION(-DOWN)
 3865.36          88.9522         -66.1448
ARCOS TO AXES E,N,VERTICAL(UP)
 66.1489          89.5765          156.145
PRINCIPAL STRESS  AZIMUTH FROM NORTH/INCLINATION(-DOWN)
 1757.31          43.6753          17.2155
ARCOS TO AXES E,N,VERTICAL(UP)
 48.7286          46.3018          72.7845
PRINCIPAL STRESS  AZIMUTH FROM NORTH/INCLINATION(-DOWN)
 2420.01          138.803          15.892
ARCOS TO AXES E,N,VERTICAL(UP)
 50.6929          136.36           74.108
      1.205 CP SECONDS EXECUTION TIME
```

APPENDIX B - SCREENING OF STRAIN RECOVERY MEASUREMENTS

SCREENING OF STRAIN RECOVERY MEASUREMENTS

Introduction

Measurements of the delicate strain recovery readings during overcoring are usually done under adverse conditions. Physical checks on the quality of bonding of strain gauges to the overcored work surface are required. The physical checks are based on loading an overcored sample and observing strain gauge responses in regard to linearity and hysteresis (3).

This generally weeds out faulty readings due to poor bonding, but even so, readings may be contained in the data set which are obtained in parts of the rock material which is non-homogeneous or possibly anisotropic.

Rock material rarely meets fully the criteria of elasticity, isotropy and homogeneity on which ground stress calculations are based. Stress determination procedures based on overcoring yield, at best, estimates of the existing stresses. However, serious distortions of the results can occur from a few strain recovery readings which belong to a different stress field (population) than that where the majority of the data had been obtained. The following procedure gives an example of how these outliers can be identified and rejected.

Identification of outliers

The following procedure is based on the normal distribution of errors, the invariance of sums of strains obtained at right angle, and the standard deviation of readings obtained in identical directions.

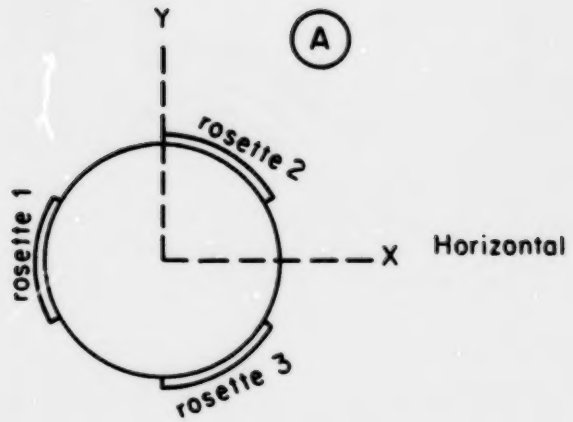
For lack of availability of a comprehensive set of doorstopper readings, a set of strain recovery measurements obtained with the South African triaxial strain cell is used as an example. The readings were obtained in one drillhole in fine-grained norite at a depth of 701 m below surface. Four overcoring tests were carried out at a location 7.6, 9.1, 9.8 and 10.4 m from the excavation boundary and the results are shown in Table B-1.

In relation to the borehole direction the gauge on each rosette formed a four gauge rectangular pattern with the rosettes spaced at 120° on the periphery. Gauge positions 3, 7, 11 = B measure in axial direction of the borehole and thus have identical measuring directions (Fig. B-1).

Table B-1 - Strain readings obtained with triaxial South African strain cell in one drillhole

Test No. / Rosette No.	Gauges	CE5 1	CE6 2	CE7 3	CE8 4	range	d_n	S
1 (same as 7, 11)	1	95	145	315	200	220	2.1	105
	2	175	170	195	160	35	2.1	17
	3*	170	215	320	230	150	2.1	71
	4	35	175	365	300	330	2.1	157
Sum of orthogonal strains:		55	15	75	-30			
2	5	800	--	1000	700	300	1.7	176
	6	355	--	955	[2265]	1910	1.7	1123 [545]
	7	90	--	315	295	225	1.7	132
	8	610	--	575	775	200	1.7	118
Sum of orthogonal strains:		-75	--	(-215)	(-2045)			
3	9	965	620	535	(1165)	630	2.1	300 - (253)
	10	620	370	390	(950)	580	2.1	276 - (135)
	11	100	195	215	230	130	2.1	62
	12	450	375	380	390	75	2.1	36
Sum of orthogonal strains:		-5	70	-20	55		mean S	214 [166]

*Directions 3, 7, 11 are identical.



Orientation of rosettes of triaxial strain cell looking down the borehole from the collar.

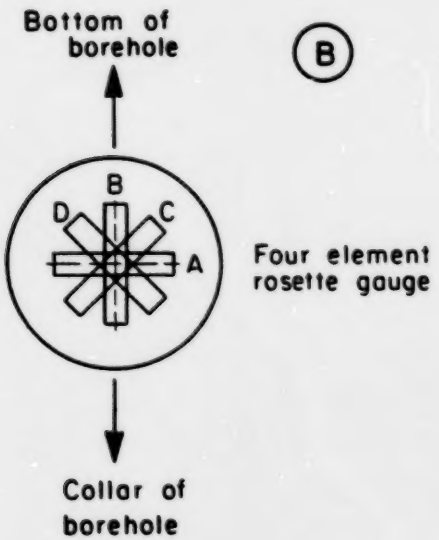


Fig. B-1 - Positions and orientation of strain gauges for triaxial strain cell installing tool.

Invariance of the sum of orthogonal strains

The advantage of a four gauge 45 degree rosette compared to the conventional three element rosette is significant because the fourth reading provides one redundant measurement. From elastic theory it has been shown that, in plane strain at a point the sum of the normal strains in two orthogonal directions is an invariant.

$$\epsilon_1 + \epsilon_3 = \epsilon_2 + \epsilon_4 \qquad \text{Eq B-1}$$

If e is the strain relief measured by any one of the gauges, and ϵ represents the type strain or model strain corresponding to e, r is the residual or difference between the measured and the model strain.

$$e = \epsilon + r \qquad \text{Eq B-2}$$

The sum of the model strains $\epsilon_1 + \epsilon_3 - \epsilon_2 - \epsilon_4 = 0$ and the direction from zero of the corresponding measurement e_1, e_2, e_3, e_4 is an immediate expression of the magnitude of the error associated with the measurements.

$$e_1 + e_3 - e_2 - e_4 = r_1 + r_3 - r_2 - r_4 \qquad \text{Eq B-3}$$

If the error r of each measurement has the variance of σ^2, both sides of the equation must have expectation values of zero and variances of $\sigma^2/4$.

The value of $e_1 + e_3 - e_2 - e_4$ from all cells should be close to zero with a standard deviation of

$$S = (\sigma^2/4)^{1/2} \qquad \text{Eq B-4}$$

$$2S = (\sigma^2)^{1/2}$$

All measurements of a cell contributing to an outlying value of $e_1 + e_3 - e_2 - e_4$ could be justifiably rejected (3).

Standard deviation of measurements in similar directions

If the four gauge rosette configuration is not available, an estimate of the standard deviation can be obtained by dividing the range of observations in similar directions by a factor d_n, which is based on the normal distribution (Davies, 1967, p. 378).

No. of observations:	2	3	4	5	6	7
d_n :	1.1	1.7	2.1	2.3	2.5	2.7

Normal distribution of deviations from group means

Another possibility of screening the data is given by plotting on probability paper the cumulative distribution of the difference of obtained strain readings and the mean of strain readings taken in the same direction. If there are n-deviations, the r-th deviation represents an estimate of the value below which 100(2r-1)/2n per cent of the observation lie. The plot should follow a straight line.

Analysis of measurements

During physical screening, which involved loading the overcored hollow cylinders, strain gauges of rosette number 2 of test CE6 showed no or a poor response and all the readings were rejected. For the remainder, the sum of orthogonal strain and the standard deviation of readings for similar directions were determined in Table B-1.

This identifies the reading 2265 (2-4) clearly as an outlier. Rejection reduces the group standard deviation of 2-6 to 545 and the standard deviation of all the group means to 166. As the group standard deviation for readings 2-6 is still excessive, and as the sum of orthogonal strains for rosette 2 in test CE7 is also excessive, reading 955 is also rejected. This leaves, then, for rosette 2 only 10 readings and shows that errors concentrate in rosette No. 2.

This leaves a total of 42 readings and a plot of the difference in strain from group means for identical strain gauge directions is given on probability paper in Fig. B-2. However, reading 355 of gauge 6 does not supply a difference from a group mean and the number of values plotted in Fig. B-2 is only 41. To demonstrate the procedure, Table B-2 is supplied.

Table B-2 - Difference from group means

		Difference for individual readings in test					
Gauge	Group mean	CE5	CE6	CE7	CE8	difference	%
1	189	-94	-44	126	11	367	1.2
2	175	0	-5	20	-15	344	3.6
3	234	-64	-19	86	-4	167	6.0
4	219	-184	-44	146	81	146	8.5
5	833	-33	167	--	-133	144	11.0
6	no average, one reading only						
7	233	-143	82	--	62	-5	50.0
8	653	-43	-78	--	122	-9	52.4
9	821	144	-201	-286	344		
10	583	37	-213	-193	367	-201	93.9
11	185	-85	10	30	45	-213	96.3
12	399	51	-24	-19	-9	-286	98.7

Readings are arranged in order of magnitude and the position on the probability axis for each reading is defined by 100(2r-1)/2x42; e.g., the fourth reading (r=4) which is 146 is plotted on the probability scale as 8.5% which indicates that 8.5% of the values have a deviation larger than +146 microstrain.

Figure B-2 shows that the majority of the data follow a straight line but readings with differences 344 and 367 deviate significantly from the normal distribution. These belong to gauges 9 and 10 of test CE8.

On the basis of the t-test, readings 950 and 1165 are rejected which brings down the mean standard deviation of all groups to 114. This leaves a relatively homogeneous set of readings. Additional refinements are possible during tensor analysis.

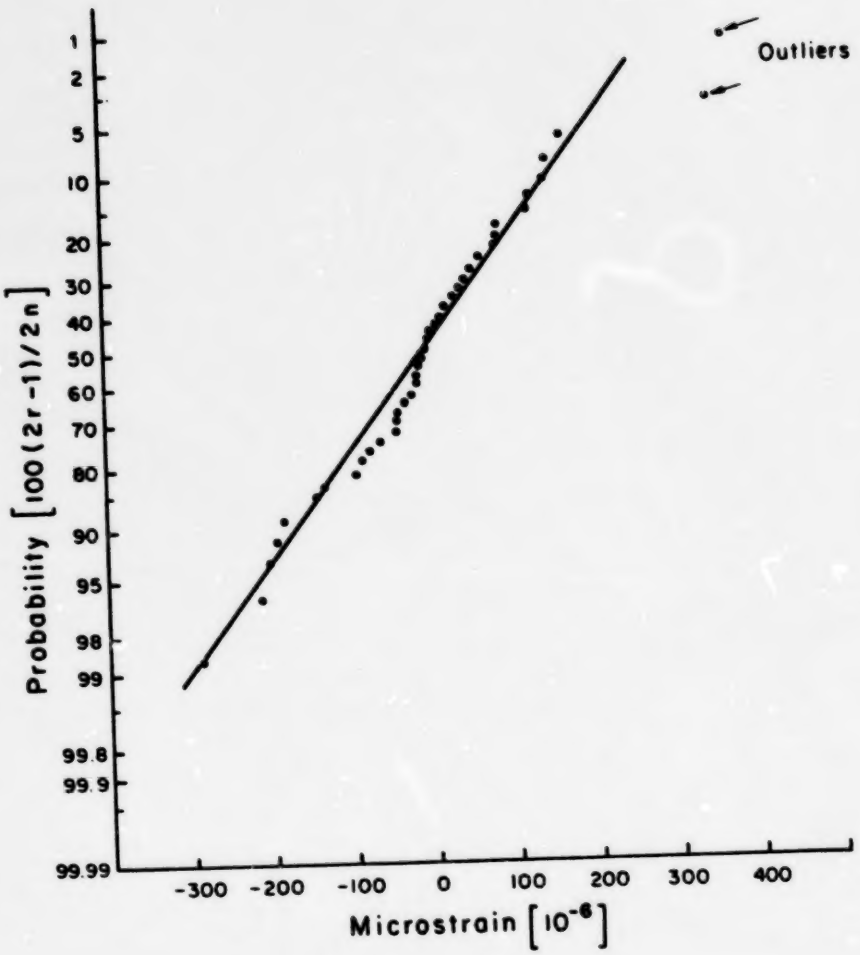


Fig. B-2 - Cumulative distribution of observed deviations from group means